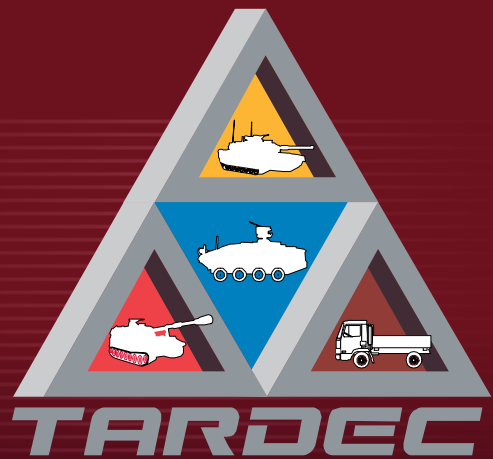

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

TARDEC Assured Fuels Initiative

7 May 2008

Noah Lieb, Hughes Associates, Inc.

Pat Muzzell, Team Lead (Acting), TARDEC

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Alternative Fuels – An Emerging Market

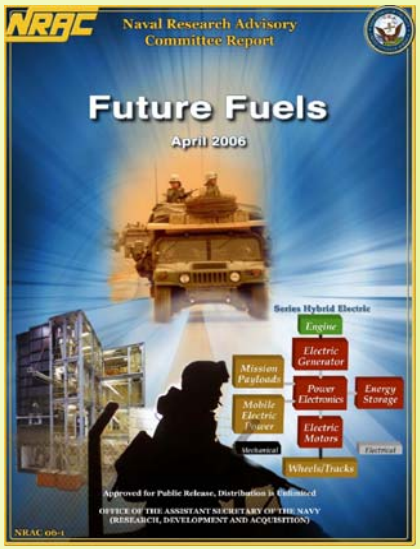
21st Century

Transportation market evolution continues, shaped by heightened concerns about energy security and the environment.

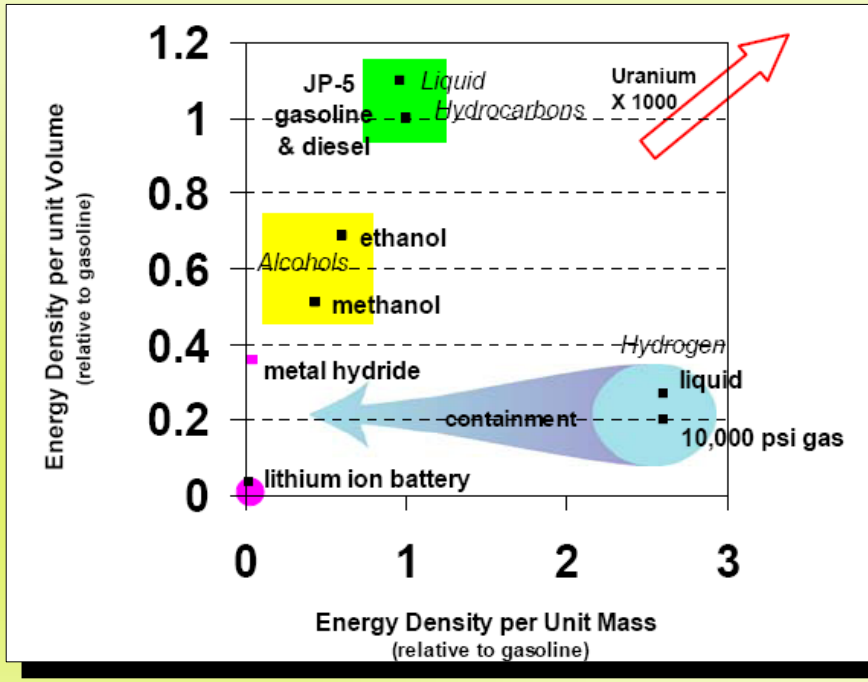
- **Alternative fuels desired in the jet/diesel fuel supply**
- **Changes driven by**
  - Legislation [Energy Policy Act of 2005], Executive Orders [EO 13423]
  - USAF Synthetic Fuels Program (goal to certify aircraft on alt. fuels by 2011)
  - Various **domestic** initiatives to produce synthetic, shale oil, and biofuels from **domestic** sources
- **Army active in assessing emerging changes**
  - Tri-department coordination of alternative fuels qualification efforts

Tactical Mobility Fuel

- **Tactical vehicle** designs impose severe limitations on volume and weight
- **Energy density** is therefore the primary consideration for fuel
- **Hydrogen presently unsuitable** as a tactical mobility fuel
  - – made using other fuels
  - – containment reduces energy density by 10X to 20X



Naval Research Advisory Committee (NRAC) Panel* Report on Future Fuels, 04/2006



NRAC Future Fuels Report, 04/2006

Liquid hydrocarbons – the ideal fuel for tactical mobility

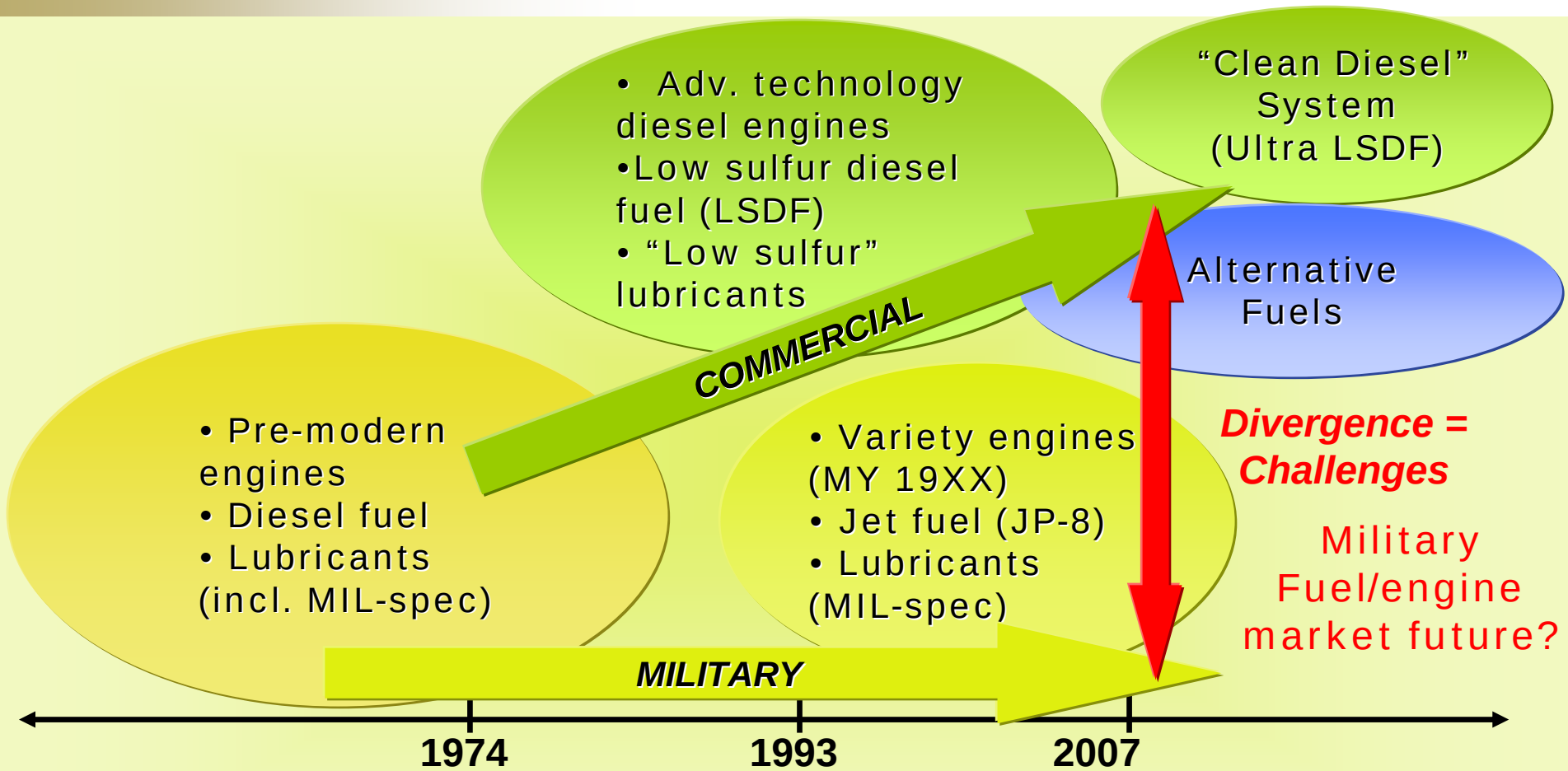
* Panel included Dr. Walt Bryzik, Chief Scientist, TARDEC

Tri-Service Position on Biodiesel

Biodiesel Not Approved For Use In Tactical Vehicles – Tactical vehicles/equipment must be ready for worldwide deployment at a moment's notice

- **Finished fuel properties vary with the different feedstock oils**
  - Wide variety of oils and greases used yield fuels of dissimilar composition
  - Second generation biodiesel will eliminate this (not yet commercial)
- **Fuel stability is poor – susceptibility to oxidation**
  - Acids/polymers formation (filter plugging, high-T deposits)
  - No guarantee fuel is stable (ASTM D 6751 is poorly enforced)
  - No guarantee use will always be in timely manner (esp. true of tactical fleet)
  - Degradation in short time-frames possible (affects ability to store equipment)
- **Low temperature properties are unacceptable**
  - Including blends with JP-8 (elevates freeze point)
- **Other**
  - Elastomer compatibility
  - Water affinity
  - Microbial growth
  - Solvency effect

Diesel Market – Military vs. Commercial (U.S.)



20th Century

Transportation market growth on cheap oil; evolution to less polluting vehicles initiated by early environmental legislation.

21st Century

Transportation market evolution continues, shaped by heightened concerns about energy security and the environment.

Challenges to Alternative Fuels

- **1988: DoD mandated JP-8 as the Single Fuel for the Battlefield**
  - JP-8 based on Jet-A + 3 additives
  - Kerosene-cut fuel; up to 3000 ppm sulfur (varies widely)
  - Need worldwide consistency in distribution and procurement
  - Alternative fuels not available worldwide (including diesel)
- **2007 EPA Ultra Low Sulfur Diesel Requirements**
  - ≤15 ppm fuel sulfur content required
  - Impacts engine design and fuel composition
  - Current national security exemptions not permanent solution
  - Combat vehicles already exempt under Clean Air Act (CAA)

Challenges to Alternative Fuels

- **Fuel additives and lubricants – must be suited to fuel/system**
  - Lubricity improvers approved for JP-8 differ from commercial lubricity improvers developed for ULSD
  - Lubricants approved for military equipment differ from commercial lubricants developed for ULSD
- **Unknowns of Emerging Alternative Fuels**
  - Limited knowledge base of fuel composition and properties
  - Suitability for use in existing/future military equipment unknown
- **Food vs. Fuel**
  - Must ensure that biobased feedstocks do not compete with food sources (i.e. non-food crops, waste, etc.)

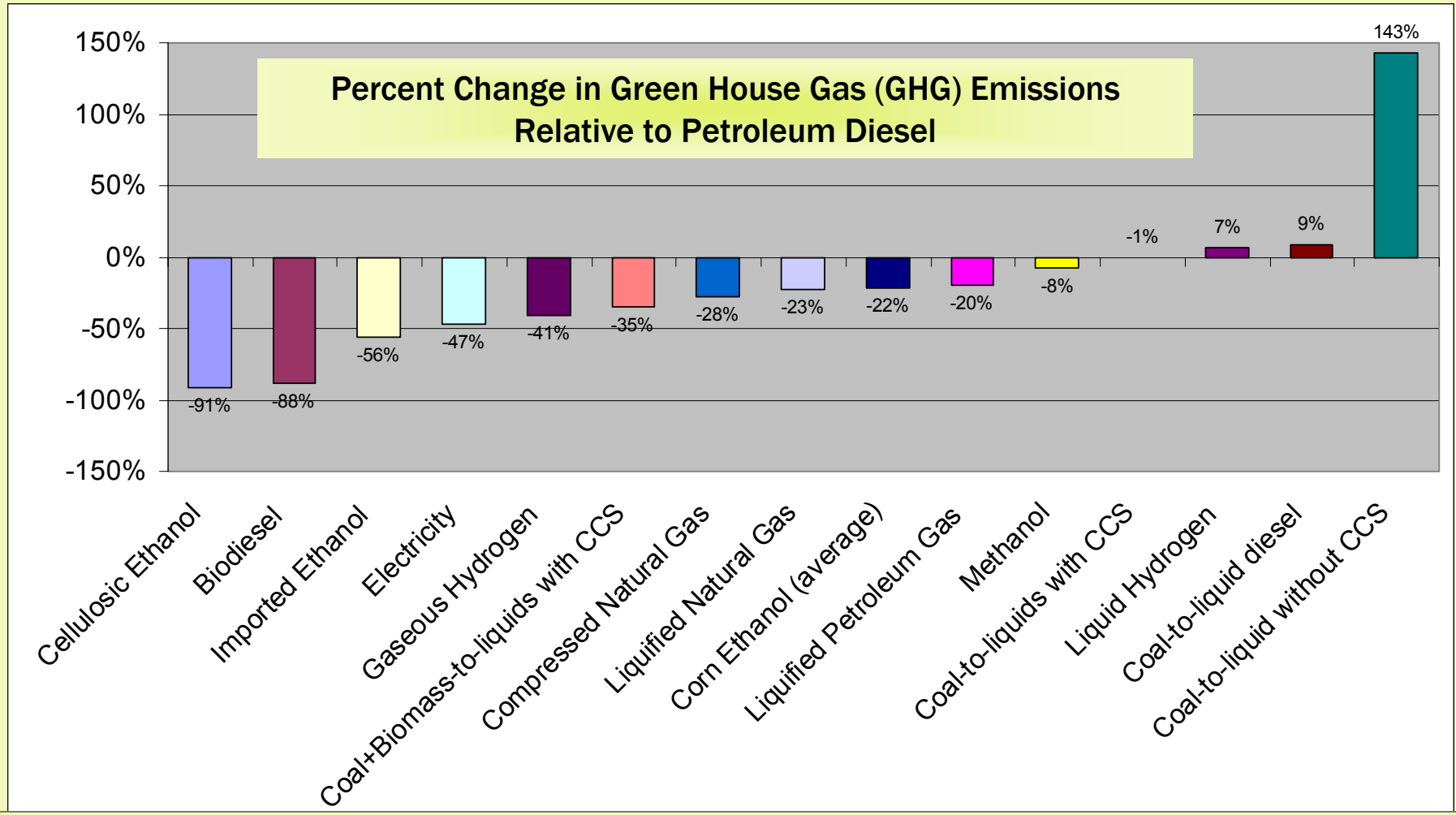
Engine Obsolescence

- **2007 (and beyond) industry engines not compatible with JP-8**
  - Current Army engines not compatible with ULSD
- **DoD granted 4 CAA national security exemptions for tactical engines; continued use of pre-2007 engines**
  - Manufacturers have provided 2004, pre-2004, or off-highway engines in most recent Army ground vehicle procurements
- **Reduced number of suppliers manufacture the older engines as EPA standards are implemented**
  - 2010 - 2007 standard fully implemented
  - 2015 - Off-highway tier IV standards fully implemented
- **DoD represents limited market share**
  - Not driving market decisions
  - Industry not designing to kerosene-based fuels

Energy Independence and Security Act of 2007

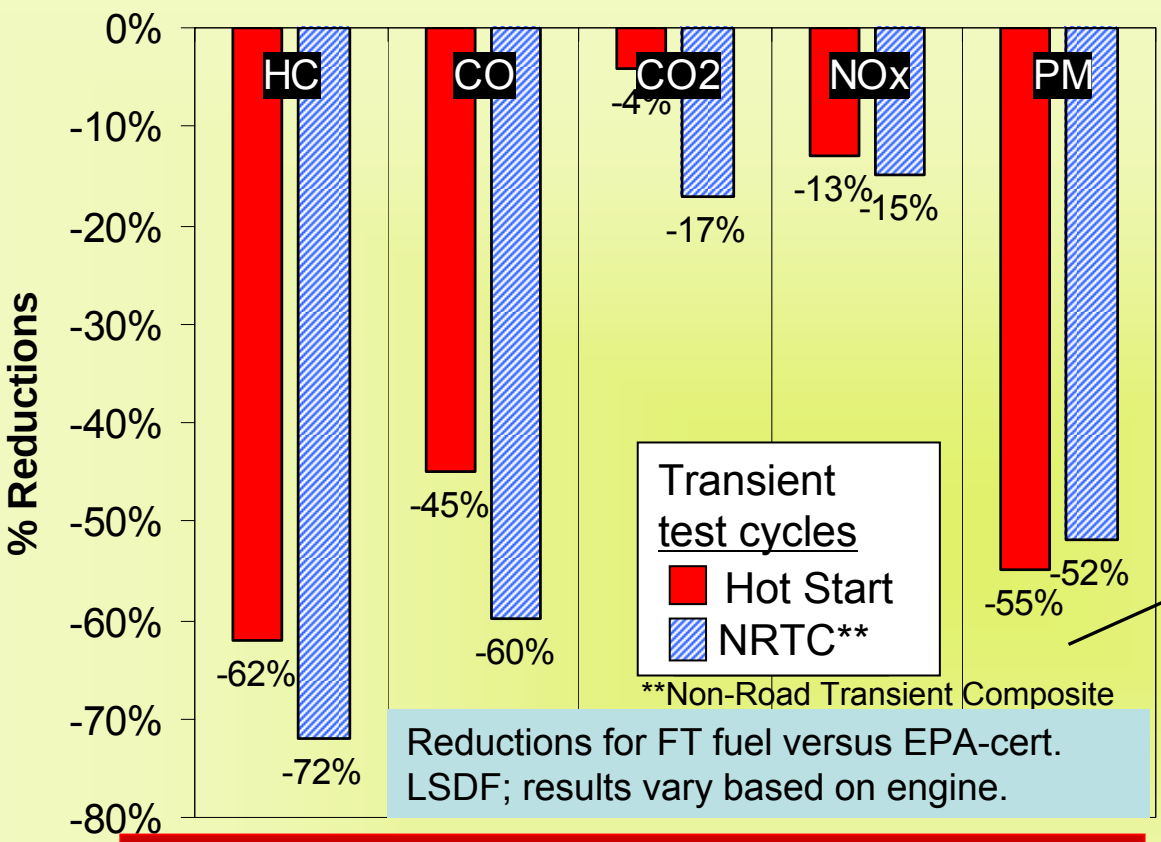
- **Became public law in December 2007**
  - Increases supply of alternative fuel sources by setting a mandatory Renewable Fuel Standard requiring fuel producers to use at least 36 billion gallons of biofuel in 2022
- **Section 526 – Federal government can not purchase fuels whose greenhouse gas emissions from creation through end-use are greater than those of fuels produced from conventional petroleum sources**
  - May affect all alternative fuels; ethanol, biodiesel, coal shale, coal-to-liquid, or oil supplies from Canadian tar sands
  - Does not restrict research or testing
- **Henry Waxman (D-CA) (Chairman of House Committee on Oversight and Government Reform) and Tom Davis (R-VA) requested that Air Force determine the long term viability of using fuel derived from coal to fuel airplanes**

Life-Cycle GHG Emissions for Various Alternative Fuels



Original source: EPA Greenhouse Gas Impacts of Expanded Renewable and Alternative Fuels Use EPA420-F-07-025, April 2007
* Preliminary results from National Energy Technology Laboratory (NETL) 10% biomass by energy

Significant Emissions Reductions Possible with Synthetic (FT*) Fuel



Reductions for FT fuel versus EPA-cert. LSDF; results vary based on engine.

FT fuel burns more completely and emissions are significantly cleaner than EPA certification low-sulfur diesel fuel.

Reference: SAE 2004-01-2961

* Fischer-Tropsch

Over 50% reduction in particulate emissions in transient mode.

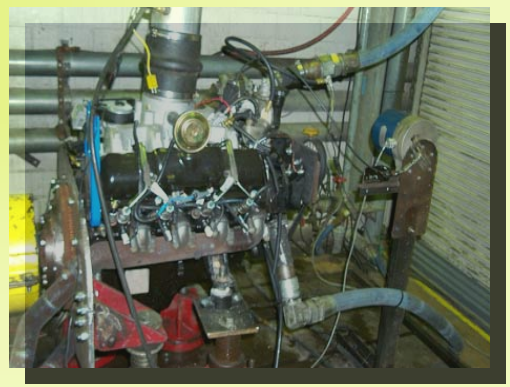


Photo courtesy of TARDEC Fuels & Lubricants Facility, Southwest Research Institute

"Leveraging Opportunities to Fill Technology Gaps."

Chemical and Physical Properties of FT Fuel vs. JP-8

- **Nothing in FT Synthetic Paraffinic Kerosene (SPK) that is not in JP-8**
  - Gas chromatograph shows similar carbon distribution
  - Evaluations by TARDEC, other agencies
  - 50:50 blends of JP-8 and FT SPK are viable as JP-8 alternatives
- **Compounds in JP-8 that are not or may not be present in FT SPK**
  - Aromatics may not be present depending on the FT reactor conditions and catalyst used and subsequent upgrade-to-finished fuel processing
    - Lack of aromatics impacts fuel density/volumetric energy density, ignition/combustion behavior, viscosity, and solvency of the fuel
  - Sulfur compounds will not be present – a benefit in that reduced tailpipe pollutants (SOx) result.
  - Trace compounds will typically not be present – impacts fuel lubricity

OSD Assured Fuels Initiative (2004 – 2006)

Vision

DoD/AT&L intends to **catalyze** commercial industry to produce clean fuels for the military from secure domestic resources using environmentally sensitive processes as a bridge to the future.

- **Role of DoD (as a catalyst)**
  - Develop fuel specifications for alternative fuels that enable use in military equipment and reduce emissions
  - Evaluate, demonstrate, and certify fuels to enable DoD to use fuels in all tactical vehicles, aircraft and ships
  - Provide a transition plan for DoD-wide deployment (begin to use alternatives to reduce dependence on petroleum)
- **DoD support leads commercial market**

Assured Fuels Initiative – USAF (2006 to present)

- SECAF supports vision of Assured Fuels Initiative
  - USAF committed to testing and certification of fleet for alternative fuels by 2011
  - USAF B-52 flight demo of 50:50 blend synthetic fuel and JP-8, summer 2006
  - USAF C-17 transcontinental flight of synthetic fuel blend, Dec 2007

TARDEC Assured Fuels Initiative Team

- **Established FY07 by National Automotive Center**
- **Initiate projects to generate necessary data**
  - Qualify alternative fuels for use in Army ground vehicles and equipment
  - Set requirements in alternative fuel specifications (protect Army engines)
    - e.g., FT IPK viscosity at 40°C ≥ 1.3 mm^2/s
- **Partner with Army Environmental Quality Technology Program**
- **Continue exploring non-petroleum alternatives to JP-8 for use in tactical equipment**

Army FT Fuel Qualification Projects

Develop data needed to assess fuel's suitability for use.

Build end user knowledge of and confidence in use of fuel.

Laboratory Evaluations → Component Evaluations → System Evaluations → Demonstrations

- **Completed**
  - Fuel chemical composition and physical properties
  - Materials compatibility evaluations
  - Fuel lubricity evaluations
  - Fuel blends studies
  - Emissions evaluation (6.5L GEP engine)
  - Caterpillar C7 engine (2 x 210-hr wheeled vehicle test cycle)
  - 10 kW tactical generators




Pat: Do you have HQ versions of these images? If not, I can add some others from the Army picture website.

Army FT Fuel Qualification Projects

Develop data needed to assess fuel's suitability for use.

Build end user knowledge of and confidence in use of fuel.

Laboratory Evaluations → **Component Evaluations** → **System Evaluations** → **Demonstrations**

- **In Progress**
  - Engine power and performance testing (NATO 400-hr test cycle)
    - 6.5L (T) GEP
    - Caterpillar C7, DDC 8V92TA, Cummins V903C (funded)
  - Test track evaluation of HMMWV
  - Tactical wheeled vehicle (5x5) pilot field demo
  - Fuel lubricity and cetane database

Pat: Do you have HQ versions of these images? If not, I can add some others from the Army picture website.




"Leveraging Opportunities to Fill Technology Gaps."

Army Environmental Requirements

Army Environmental Requirements and Technology Assessments (AERTA) - PP-7-07-01

"Advancements must be made in developing FT fuels that are compatible with Army systems. Feed stocks should include biomass and bio-wastes, particularly those created at Army installations, to develop FT fuels that meet Army (DoD) requirements for use in combat and tactical vehicles and equipment … "

- **TARDEC building program to meet requirement**
  - Integrate AERTA requirements with Assured Fuels Initiative
  - Develop renewable feedstocks and fuels suitable for training and combat from:
    - Non-food crops
    - Waste from food/animal/wood
    - Mixed waste/garbage (long term)
  - Leverage existing FT research on non-sustainable coal or shale oil

Future

- **Develop a more sustainable and less polluting assured fuels supply through development and commercialization of jet/diesel fuels that:**
    1. are made from renewable resources
    2. have low life-cycle greenhouse gas emissions
    3. have fuel specifications allowing their use in DoD/Army weapons systems and platforms with acceptable performance and durability

Commercially-Viable Conversion Processes

Ultra-Sustainable Renewable Battlespace Fuels

"Leveraging Opportunities to Fill Technology Gaps."

Questions?

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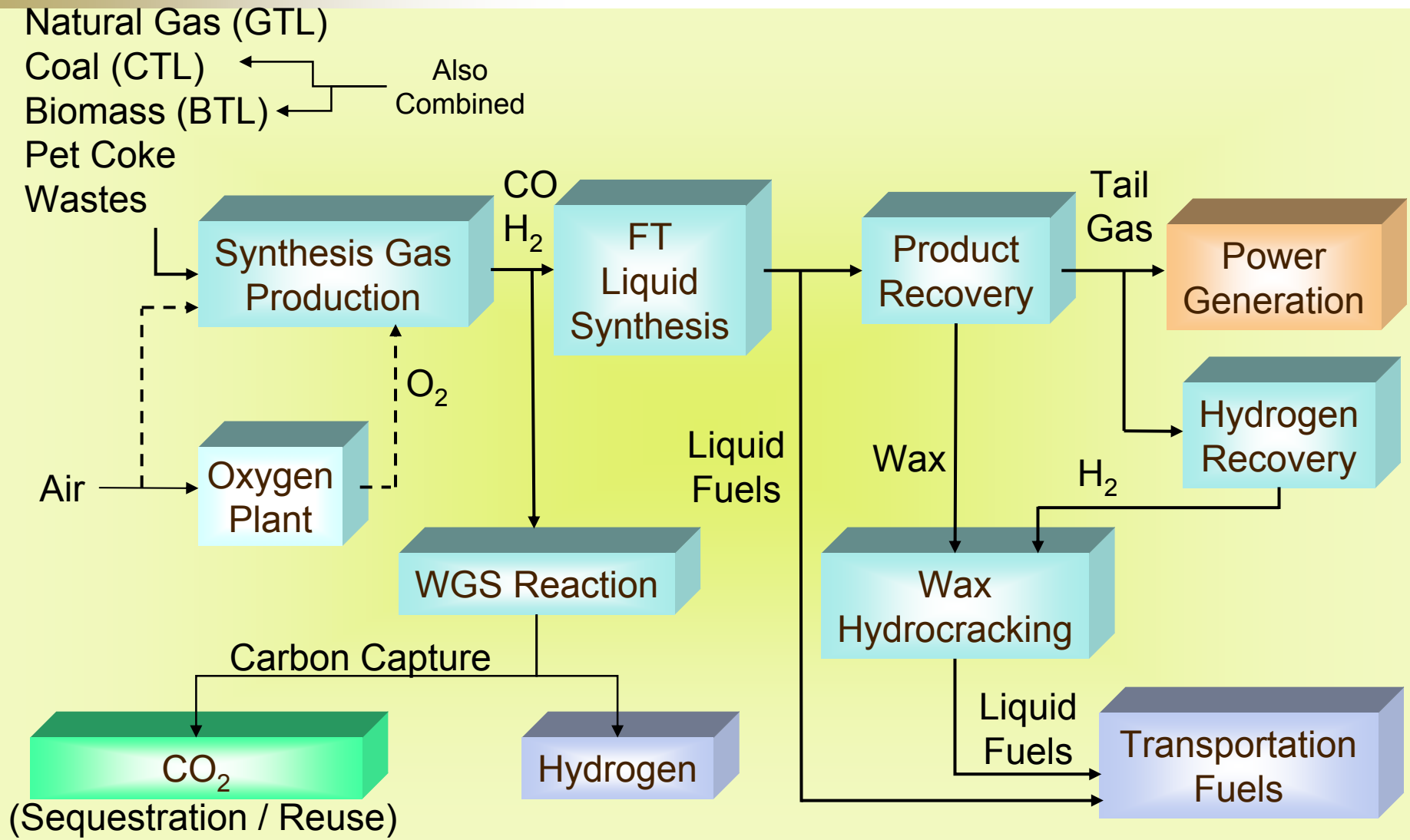
410-737-8677

References:
http://www.onr.navy.mil/nrac/

Back-up Slides

Fischer-Tropsch Technology



"Leveraging Opportunities to Fill Technology Gaps."

Flexible JP-8 Pilot Plant Program

- **DoD-coordinated study of FT fuel**
  - Congressionally funded FY02, FY04, FY05 effort with Syntroleum Corp.
  - Managed by TARDEC National Automotive Center (NAC)
  - DoD Tri-Services' fuels labs, along with DOE-National Energy Technology Lab, began research and testing of FT fuel
  - Coordinated spec development with Coordinating Research Council Aviation Committee – key aviation industry stakeholder group influencing commercial jet fuel spec (ASTM D1655)

Photo courtesy of Syntroleum Corporation

Syntroleum FT Plant

- Co-funded by DOE Ultra-Clean Transportation Fuels Demonstration Program
- Produced jet/diesel fuels from natural gas for DoD, DOE, DOT projects; plant shutdown in 2006

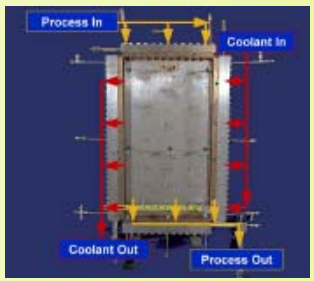
Success Story: Microchannel Processing Technology (MPT)

Key Objectives

- Develop and build two microchannel reactors
  - FT reactor: convert CO + H_2 to long-chain hydrocarbons
  - Hydrocracker: upgrade FT wax to finished fuel

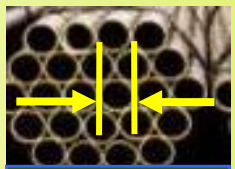
Success Milestone

- FT reactor demo
  - Performance indicates commercial viability

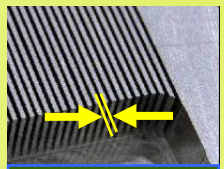


The Technology

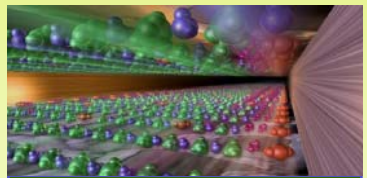
- Stacks of closely spaced thin plates form microchannels
- Process fluids pass through channels where chemical conversions / heat exchange occur
- Heat generating channels typically interlayered with cooling channels
- Individual microchannels < 0.2" wide – small heat and mass transfer distances, high throughput rates



~5 - 15 cm
Conventional



~0.1 - 0.3 mm
MPT



Accelerates chemical processes by factors of 10-1000x

The Technology Benefits

- Extremely high rates of heat and mass transfer
- More active catalysts can be used
- Smaller, more productive reactors
- More control of reactions under optimum conditions
- Avoids undesirable by-products
  - Higher product yields
  - Lower purification requirements
- Lower capital cost possible for large and small-scale processes

The Applications

- Large-scale, commercial in energy/chemical markets
- Natural gas upgrade to monetize remote/off-shore sources
  - Alliance announced 11/20/2007 to commercialize off-shore GTL by 2012
- Processing and/or production of
  - Hydrogen, synthetic fuels
  - Emulsions and polymers
  - Ethylene and other chemicals
- Good potential in biomass-to-liquids (BTL) applications
  - Conventional technology cost-prohibitive at scale practical for biomass
  - Microchannel technology allows scale down to levels practical for BTL for production of fuels such as FT synthetic kerosene to blend with JP-8

Military Interest

Commercial-scale conversion of domestic resources to fuels suited for use in tactical/combat equipment.

Assured Fuels Initiative

"Leveraging Opportunities to Fill Technology Gaps."

Recent TARDEC Coordination

- **Army AMRDEC Aviation Engineering Directorate (AED)**
  - Facilitated meeting of AED, fuel specialists - key engine OEMs, and AFRL to explore leveraging of OEM engine certifications for synthetic jet fuel blends
    - Possibility to reduce testing of Army-specific aircraft engines
    - Some potential opportunities targeted for AED follow-up
- **Commercial Aviation Alternative Fuels Initiative (CAAFI)**
  - Launched in October 2006, mirrors the OSD Assured Fuels Initiative
  - Certification Qualification (CQ) Panel (1 of 4) led by FAA
    - Aviation Industry: fuel, airframe, and turbine engine manufacturers
    - DoD: Air Force, Navy, Army (AMRDEC AED), Defense Energy Support Center
- **DESC Joint Fuel Forum 11/16/2007**
  - DESC working next FT IPK buy for continued qualification of 50:50 blends
  - Army volumes required (blend): FY08 – 16K gal and FY09 – 20K gal

Assured Fuels Initiative Team

Market Connection

Industry / Academia / Educational Outreach

- **Velocys:** Microchannel Processing Technology for Synthetic Fuel Manufacturing
- **CFFS:** Military Synthetic Fuels Research Program
- **NextEnergy / Wayne State Univ.:** National Biofuel Energy Lab; Optimization of Multi-Fueled Gensets (Titan Energy) for Homeland Security
- **U of Detroit-Mercy:** Michigan-Ohio University Transportation Center
- **FSSI:** A Study of Bio-Based Fuels
- **DSC:** Transportation Fuels Gallery

CFFS

NEXTENERGY Economic Security through Energy Diversity

WAYNE STATE UNIVERSITY

RITA U.S. Department of Transportation Research and Innovative Technology Administration University Transportation Centers

MIOH-UTC

Alternate energy and system mobility to stimulate economic development.

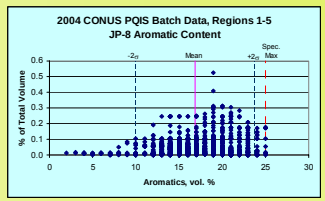
Fuel Evaluations

TARDEC Fuels & Lubricants Lab

- Fuel Composition
- Fuel Properties
- Materials Compatibility
- Synthetic Fuel Blends Study
- Fuel Lubricity Improver Additive Detection Method

TARDEC F&L Research Facility (TFLRF) at Southwest Research Institute (SwRI™)

- Fuel Lubricity Database
- Fuel Ignition Characteristics Database



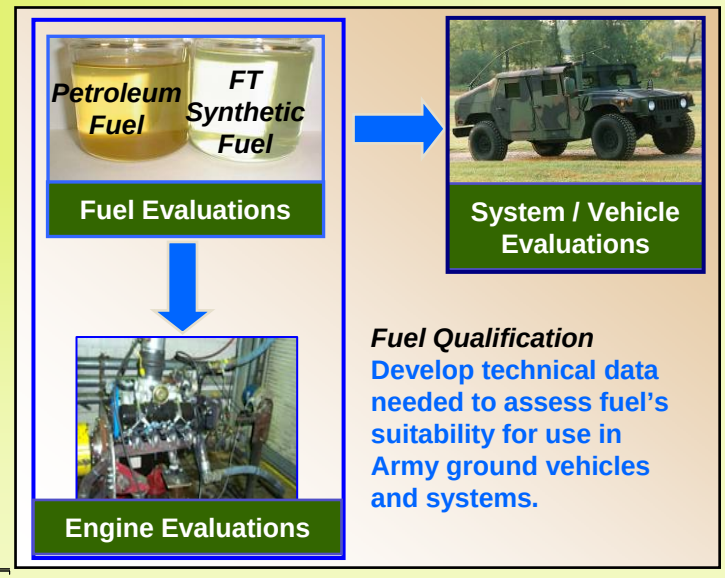
Engine / System Evaluations

TARDEC Propulsion Lab

- Fuel Ignition Behavior
- Engine Performance & Durability for Synthetic Fuel Blends
  - GEP 6.5L Turbo
  - CAT C7
  - DDC 8V92-TA
  - Cummins 903

TFLRF at SwRI

- Engine Emissions Data
- Military Genset (10 kW) Performance of Synthetic Fuel Blends
- CAT C7 Engine Performance & Durability of Fully Synthetic Fuel
- TWV Test Track Performance of Synthetic Fuel Blends
- TWV Pilot Field Demo of Synthetic Fuel Blends



Fuel Qualification

Develop technical data needed to assess fuel's suitability for use in Army ground vehicles and systems.

"Leveraging Opportunities to Fill Technology Gaps."

Assured Fuels Initiative Team

Do Our Part and Be Better At Working the R&D Process – A Continuous TARDEC Process!

KNOWLEDGE

Alternative Fuels Emerging Market

- Tap Tri-Service knowledge base, maintain awareness of alternative fuel strategies, programs, and direction
- Tie into DARPA biojet program
- Stay current with activities of key fuel manufacturers
- Learn about emerging alternative fuels market; develop and communicate understanding of manufacturing technologies, fuel data, drivers and trends to key stakeholders
- Conduct testing, as justified, to augment understanding of alternative fuels, their properties, and suitability for use in Army engines, vehicles and fuel distribution systems
- Continually improve technical expertise in fuels, and related topics, e.g., fuel additives, interactions with fuel-wetted hardware

INVESTMENT

Programs & Plans

- Provide inputs into the decision making process for core investments, e.g., the TARDEC P&E IPT
- Seek opportunities to leverage other programs/dollars for benefit of understanding and/or demonstrating the suitability of alternative fuels for use in Army equipment
- Scope and manage congressionally funded projects to maximize their benefit to the Army
- Invest in education, training, and development of team personnel, improving skills and competencies to achieve greater team contributions to TARDEC / RDECOM / Army

DIRECTION

Assessments & Recommendations

- Complete and document assessments of alternative fuels, in collaboration with key TARDEC associates:
  - analyze data from testing,
  - develop conclusions, and
  - make recommendations regarding strategy, next actions
- Attain peer reviews of assessments with experts and appropriate organizations, e.g., ARC, SAE, CRC, OEMs
- Influence emerging alternative fuels specifications to:
  - maximize Army fueling flexibility
  - minimize detrimental impacts to Army fuel-wetted hardware

"Leveraging Opportunities to Fill Technology Gaps."

CRC AV-02-04 Project:
Approval Process for Synthetic Jet Fuel

- **Synthetic jet fuel specifications development**
  - Coordination with aviation industry a tenet of Flexible JP-8 Pilot Plant Program
  - TARDEC initiated coordination through the **Coordinating Research Council (CRC)** Aviation Committee in 2003
- **TARDEC led Task Force – Synthetic Jet Fuel Approval Process** (FY05-FY07)
  - Oversight on CRC Project AV-02-04; contractor working with stakeholders to define and document the approval process to allow use (approval) of synthetic jet fuels in commercial aviation sector
  - Task Force members from across Aviation Industry
    - Boeing, GE, Honeywell, Rolls-Royce, Pratt&Whitney (manufacturers)
    - NASA, DESC, USAF, USN (government)
- **CRC Report issued January 2008**
  - "Development of the Protocol for Acceptance of Synthetic Fuels Under Commercial Specification“
  - Protocol intends to establish that once synthetic fuel/blends are accepted by aircraft engine OEMs, the fuel is also “approved” under the commercial aviation fuel spec
  - Acceptance protocol helps in establishing the market for synthetic jet fuel

Blends Study

- **FT IPK/JP-8 Blend Properties**
  - Compared properties of blends with typical properties of JP-8 (CONUS, 2004)
  - Determined properties of blends (up to 50% FT IPK) generally fell within typical "property box" of JP-8
  - Study documented in **SAE Paper 2006-01-0702**
- **Follow-on study looked at typical JP-8 in use at five Army installations in CONUS**
  - Determined that at four of the five installations blends with the maximum reduction of 50% by volume petroleum content (JP-8) are possible
  - Study results documented in **2007 IASH Conference Poster** (see next slide)
    - Poster presented at the 2007 International Association of the Stability, Handling and Use of Liquid Fuels (IASH) Conference